fall in most of Hawaii. The next three curves are presented to show the marked influence of altitude, beginning with the Kalahiki station at 750 feet and followed by two other records in the immediate neighborhood at altitudes of 1,500 and 1,800 feet, respectively; and finally the curve at the bottom is a composite one made from all the available rainfall records of both north and south Kona. The bottom curve shows that the months of greatest rainfall coincide with the growing season of sugar cane in the Kona districts. These districts being in the shadow of the mountain masses of Mauna Kea and Mauna Loa are, as noted above, not subject to trade winds, and thus less moisture is lost by evaporation than in districts having a northeast exposure.

SOME OUTSTANDING AEROLOGICAL PROBLEMS

By WILLIS RAY GREGG

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It is a very good thing to pause occasionally in our work, take stock of what we are doing and endeavor to determine what new lines should be taken up and what changes, if any, in the old should be made. It is, I think, peculiarly fitting that we do this now when we are considering the work of Doctor Meisinger, for he was, to a greater degree than any one else I have known, absorbed with the fascination of ferreting out the secrets of the atmosphere. Less than a week before he left for his work at Scott Field we talked for an hour of the problems that lie before us, some of which he planned to attack upon his return, and in all of which he was ready and eager to give his assistance and advice. And so this brief talk constitutes, in a sense, a recapitulation of what we discussed at that time. I shall be glad indeed if it leads some aspiring student, by a contribution along one or more of the lines suggested, to earn an award under the Meisinger Aerological Research Fund, concerning the purposes and present status of which you are shortly to hear.

The problems I shall name (I can do little more than name them, in the time allotted) are not given in any order of relative importance, except that the last one is, to my mind, the *most* important.

1. *The diurnal variation of meteorological elements at different heights.*—This is, perhaps, a subject of greater theoretical interest than of practical value, although it may be pointed out that the diurnal variation in wind speed at moderate heights plays an important part in determining regular flight schedules. We know that the phase characteristic of the surface, viz, maximum velocity in the afternoon, minimum in the early morning, is reversed above 100 meters; that, between about 300 and 1,000 meters the diurnal amplitude is large, amounting to 3 or 4 m. p. s., on the average; and that, above about 1,500 meters there is essentially no variation.

Studies of the temperature variation agree in showing a diminishing amplitude from the surface to about 1 to 2 kilometers, where it is very small, less then 1° C., but these studies give contradictory results at greater heights. Some investigators claim a reversal of phase in these upper levels. More recent and more abundant data at Drexel and other stations in this country, however, indicate that the phase is essentially like that at the surface and that the amplitude is about 1° C. These later data represent practically all varieties of weather conditions, and the same results are shown for all parts of the year. The investigation is, however, in a preliminary stage only. It should be pushed to completion, and extended to the other meteorological elements, such as humidity, pressure, density, wind, etc. The data we now have, as the result of numerous series of successive kite flights covering periods of 24 to 30 hours, are ample for a complete and authoritative analysis of this problem.

2. *Winds and weather along airways.*—This is a problem of immediate practical value. In order intelligently to determine regular flight schedules for commercial or other purposes it is essential to know, for different sections of an airway, the resultant wind at flying levels, the percentage frequency of wind speeds above certain limiting values and the percentage frequency of occurrence of weather conditions, such as widespread heavy precipitation, blizzards, etc., that make flying impossible or at least hazardous. Studies along this line have already been completed for Oklahoma and east Texas and for the New York-Chicago airway. They should be extended to all sections of the country where regular flying, commercial or otherwise, is likely to develop, and preferably this should be done before such development takes place. For much of the eastern and central portions of the country suitable data for this problem are now available.

3. *The free-air in thunderstorms.*—Thunderstorms constitute the most difficult condition of the atmosphere to explore. For man-carrying aircraft to attempt this is suicidal; pilot balloons quickly disappear in the clouds, and even while in sight yield data of doubtful value, owing to vertical air movements, unless observed with two theodolites; and kite flying frequently results in destruction of the kite line and damage to the equipment, besides involving the possibility of injury to personnel. Nevertheless, a considerable mass of data has been collected, mostly perhaps immediately before and after the thunderstorms, but partly also within them. It is believed that an analysis of the data in hand would be fruitful, and would admirably supplement some recent statistical studies.

4. *Clouds.*—Notable contributions to this subject have been made in the past 30 years or so, and much of our knowledge of the larger features of the planetary circulation are based upon these studies. The field is far from exhausted, however. Little is known, for example, as to the average and extreme thickness of the different types, the variations in height, thickness and speed with latitude, in different parts of cyclones and anticyclones and in elevated as compared with low-lying regions. We need to know more than we do now with reference to lapse rates in clouds and their relation to precipitation. Data for these studies, although perhaps not adequate for a final settlement of them, are nevertheless quite abundant, through the observations we have made with kites and pilot balloons, and would, it is believed, well repay earnest effort on the part of those who can undertake their analysis. These data should of course be considered and combined with the results of earlier investigations, such as those of the International Cloud Years. The latter yielded information of immense value. It seems certain that the more recent data will supplement those where they were weak and bring the whole subject to a more satisfactory status than has heretofore been possible.

5. *The free air in the Tropics.*—The planetary circulation more closely approaches its ideal state in this region than in any other. It is here comparatively free from

disturbances such as the cyclones and anticyclones that characterize the temperate and subpolar zones. It is therefore an inviting field, but it must be explored more fully before it can be attacked and disposed of in anything like final form. Already, however, there is available a considerable amount of data, and some important contributions have been made, among the more recent being those of Van Bemmelen in Java and Harwood in India. In our own hemisphere we have a very good series of pilot-balloon observations at San Juan and Key West, and shorter series at Santo Domingo, Curacao, and the Canal Zone. Similar data have been obtained by this country in Hawaii and Guam. A study, based upon all this material, is now in preparation, but other studies from different angles would undoubtedly be fruitful. Unfortunately there are lacking temperature and humidity data, essential for any complete discussion. These can only be secured, so far as we know now, from sounding-balloon ascensions, and the prospect of work along this line at an early date is not promising. Nevertheless, the problem is presented at this time as an attractive one, since suitable data are available for preliminary discussions, and these will be of real aid in later studies when more data have been collected.

6. *The free air in the polar regions.*—This is certainly one of the most important problems before us, and, equally certain, its elucidation is one of the most difficult. It is important, particularly to us in this country and to our neighbors in Canada, because of the intimate relations between the weather along the polar-region border and our own subsequent weather. It is difficult, because the methods of exploration ordinarily employed are for the most part not suited to those regions. Thus, the use of sounding balloons would be very expensive, since very few would be found and returned. Because of remoteness from sources of supply and because of the severity of climatic conditions, kite flying would be extremely difficult. Pilot balloons alone would seem to be practicable, and even these would not be entirely satisfactory in winter, because of continuous or nearly continuous darkness. Besides, they give information as to wind conditions only. This problem can not therefore, at the present time, be presented to students. The necessary data for its solution must first be secured. It is a pleasure to note that a beginning has been made with pilot balloons by the Canadian Meteorological Service. It is our hope that this country may soon follow our neighbor's lead with similar observations in Alaska.

7. *The stratosphere.*—The two problems that I have just now presented include exploration and investigation of the stratosphere as well as of the troposphere. In the Tropics we have a splendid series of data at Batavia, and that is all, except a few scattering observations here and there. In the polar regions we have no data whatever for the stratosphere. Such data are urgently needed, for until they are at our disposal we are compelled to leave unfinished and uncertain *any* discussion of planetary circulation.

Even in our own latitudes, where observations at great heights can be most easily made, there is need for much more information than we at present possess. Some of the European countries have covered the field quite well. In the United States and Canada we have just about enough data to make us want more. We do not know at all precisely the latitudinal and annual variation in the height and temperature of the stratosphere. Similarly, the variation with surface pressure and temperature is not clear. Nor can we add materially to our knowledge in these matters by future studies of the data now available, for, owing to the revolutionary significance of this subject, it has elicited the interest of the world's ablest meteorologists, so that practically everything has been written that is possible until more complete and better distributed observations are secured. What we have in mind, so far as this country is concerned, is a number of series of simultaneous, daily soundings at a string of stations from North Dakota to Texas, at least four such series, well distributed through the year, each one covering at least a month. These should be followed by similar series near the Pacific and Atlantic coasts, and if possible there should be included extra observations at times of unusually interesting conditions at the surface; also several series of successive soundings at intervals of two or three hours for studies of the diurnal variation at great heights. This, it is true, is an ambitious program, but, equally true, it must be carried out before we can settle many of the questions that now perplex us. The problem can not be presented to students at this time, for, as earlier stated, about everything possible has already been done with the data available, but to students of the future it can be recommended as offering opportunity for the display of a high order of talent in research.

8. *The free air in cyclones and anticyclones.*—Happily, for this problem there is already available, in conveniently usable form, an abundance of data. Several contributions to the subject have been made and others are now in preparation, yet it can truly be said that we have barely scratched the surface. The origin, growth, and decay of these pressure systems, their direction and rate of movement, their height, the distribution of the meteorological elements in them at different heights, the variations in this distribution with latitude, season, topography, etc., and its relation to precipitation are only a few of the many phases of the subject that are worthy of the best efforts of well-trained students. More and more it is coming to be realized that the study of individual cases offers the most promising results. Some of us believe that Doctor Meisinger's analyses of three remarkable cyclones in the United States will occupy a high place in the final estimate of his contribution to meteorology. In these analyses he used all available cloud observations, and free-air temperature, pressure, humidity, and wind data from kite and pilot-balloon observations. This problem is presented as one of the most attractive at this time, because the necessary data are in large measure now available and because these systems, cyclones, and anticyclones, are the dominant features in our day-to-day weather.

9. *Application of free-air data to forecasting.*—Only a few of us are forecasters, and a still smaller number are conspicuously successful forecasters. Yet the chief end and aim of our meteorological existence is the accurate forecasting of weather. Certainly this is true of us in the Weather Bureau, as any one can see by a perusal of the organic act under which the bureau operates. Emphasis is there placed upon *forecasting*, almost to the exclusion of everything else. And it is right that this should be so. No matter what the lines along which our individual efforts are directed, they all finally meet and center in the Map Room. This problem then, the last that I am presenting, is thought to be by far the most important of all. Obviously, new light on those already named will contribute to the elucidation of this one, but just now we are considering the more direct and more specialized studies that should be made, and for which there are already abundant data.

It is generally accepted that the movements of cyclones and anticyclones bear a close relation to the air move-

ment in the upper levels. In the eastern and central portions of the United States this relation appears to be closest for cyclones at about 3 to 3½ kilometers and for anticyclones at about 1½ to 2 kilometers, somewhat higher in each case in summer than in winter. These are averages; in individual cases there are wide variations, owing chiefly to variations in temperature distribution, both horizontal and vertical. What is needed is an accurate representation of free-air pressures, and therefore winds, at different levels up to about 5 kilometers; in other words a series of synoptic maps for these levels similar and supplemental to the one regularly used for the sea level plane. It was to this problem that Doctor Meisinger applied his fine training and talents, and it was in an effort to secure additional data for its better understanding that he gave his life. He realized fully that he had made a beginning only, but he also believed, and many of us have the same conviction, that he was on the right track. Material modification would undoubtedly have to be made in details (Doctor Meisinger himself expected this), but the purpose and much of the general plan are undoubtedly sound. The purpose was not to have these free-air pressure maps take the place of actual observations, but to supplement them, since the latter can not always be made, at any rate with methods at present employed. This problem then is presented as the most important now before us—one demanding talents and training of the highest order.

Summary.—There are of course innumerable other problems awaiting our attention, but the emphasis in this paper is placed upon the word "outstanding." Of those presented there are seven for which data are already available, in part at least, viz, diurnal variation; winds and weather along airways; the free air in thunderstorms; in clouds; in the Tropics; and in cyclones and anticyclones; and the application of free-air data to forecasting. Studies along these lines have been and are being made but the field is wide open. The problems are especially recommended to graduate students who aspire to compete for grants from the Meisinger Aerological Research Fund. The purpose of that fund, as stated, is "the promotion of aerological research, * * * to the end that the type of research in which Doctor Meisinger was engaged shall be encouraged," and all of these problems meet that specification. Later, when the necessary data shall have been secured, the other two problems, viz, the free air in the polar regions and the stratosphere, will in their turn provide opportunity for researches which can hardly fail to yield results of far-reaching value in theoretical and applied meteorology.

AVERAGE FREE-AIR WINDS AT LANSING, MICH.

By C. L. RAY

[Weather Bureau Office, Lansing, Mich., January, 1925]

At the end of May, 1924, the pilot-balloon flights at the Lansing station had reached a total of approximately 2,100, covering a period of five years, June, 1919, to May, 1924, inclusive. These data have been summarized and the results are presented in this paper, which is, in some respects, a revision of an earlier paper of the same title,[1] although additional features, such as resultant winds, and a classification according to surface direction, are now included. The observations have in all cases been made with one theodolite, and the data are therefore subject to the errors of that method. From numerous two-theodolite observations it has been shown, however, that these errors are as a rule not large and that they are quite negligible when mean values are considered, as in the present paper.[2] Until August 1, 1921, two observations were made daily, at 7 a. m. and 3 p. m.; since that time there has been one only each day, that of the afternoon.

Lansing is located about midway between Lakes Michigan and Erie. Its geographic coordinates are: Altitude, 263 m.; latitude, 42° 44′ N; and longitude, 84° 26′ W. It lies close to the tracks of most of the cyclones that cross the country, with the exception of those that come up the Atlantic coast. The large percentage of days with precipitation or at least cloudiness and with strong winds, associated with these storms, renders the location unfavorable for the best results, so far as continuity of record and the attainment of a high average altitude are concerned. Nevertheless, the records of the period show that the loss of flights for all seasons is only 12 per cent. A maximum of 20 per cent reached during the winter months is balanced by a minimum of less than 5 per cent during the summer, while the spring and autumn show a failure to secure flights 11 per cent of the time.

Table 1 contains the seasonal and annual totals of all flights made during the five-year period. This total of more than 2,100 flights offers a satisfactory basis for the computation of average values. In the upper levels the number of flights available becomes smaller, as different things occur to terminate the individual ascensions. However, there are 1,007 observations at 3,000 meters, 682 at 4,000 meters, 489 at 5,000 meters, and 341 at 6,000 meters. At higher levels observations are too few to give dependable means. In all cases heights are given above the surface.

TABLE 1.—*Number of pilot-balloon ascensions, at Lansing, Mich.*

Altitude (meters)	Spring	Summer	Autumn	Winter	Annual
250	532	604	534	454	2,124
500	507	598	518	405	2,028
750	481	583	484	343	1,891
1,000	458	573	439	308	1,778
1,500	396	529	381	247	1,553
2,000	349	457	339	209	1,354
2,500	293	398	277	185	1,153
3,000	251	355	241	160	1,007
3,500	208	285	193	124	808
4,000	169	265	157	105	696
4,500	148	233	120	72	573
5,000	123	212	103	54	492
6,000	81	156	68	36	341

In Tables 2 and 3 are shown, respectively, the number of flights with differing surface directions and the percentage-frequency of winds from the various points of the compass. The percentage-frequency of winds from different directions at the surface and at 2 and 6 kilometers for the summer, the winter, and the year is also shown in Figure 1. It will be noted that during the spring months 45 per cent of the surface winds have a south component, during the summer 47 per cent, in the autumn 53 per cent, and in the winter 47 per cent. North surface components are observed 43 per cent of the time in the spring, 40 per cent in the summer, 30 per

[1] MO. WEATHER REV., December, 1922, 50: 642-645.
[2] Haines, W. C., Ascensional Rate of Pilot Balloons. MO. WEATHER REV., May, 1924, 52: 249-253.